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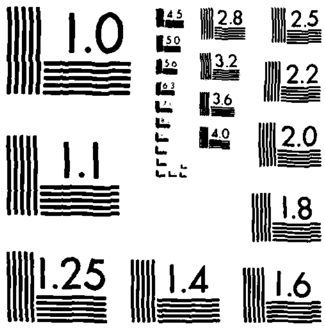

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SIMULATION OF HIGH +Gz ONSET IN THE DYNAMIC ENVIRONMENT SIMULATOR

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BURLINGTON, MA

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
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FOR THE COMMANDER

James C. Rock

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Associate Director
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This report documents a unique approach of coupling the cab-axis degree of freedom to the main arm motion of the Air Force Aerospace Medical Research Laboratory human centrifuge, or DES (Dynamic Environment Simulator). This technique of simulating high +Gz onset was successfully demonstrated and documented. Gz onsets ranging from 0.45 Gz/sec to 2.875 Gz/sec were investigated and eleven subjects completed the study. Peripheral light loss (PLL), a precursor to loss of consciousness, was recorded in all eleven subjects using this technique. Three G-tolerance scenarios were investigated; relaxed subject/no anti-G suit inflation, relaxed subject/anti-G suit inflation and straining subject/anti-G suit inflation. A semi-circular light bar was used in the DES cab to monitor peripheral light loss of subjects. The PLL results compare favorably with similar results in the NADC centrifuge where subjects faced tangentially and were subjected to +Gz only rather than +Gx and then +Gz as in this experiment. These results give a strong indication that this technique can be used to simulate high +Gz onset in the evaluation of anti G-valves, suits and straining maneuvers.

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PREFACE AND ACKNOWLEDGEMENTS

This report documents a series of in-house experiments conducted under the Acceleration Performance in Advanced Operator Systems workunit (72312501) at the Biodynamics and Bioengineering Division of the Air Force Aerospace Medical Research Laboratory (AFAMRL) at Wright-Patterson Air Force Base, OH.

The authors wish to extend their appreciation to Ms Barbara O'Lear (Raytheon Service Co.) for her development and refinement of the profiles and data recording and valuable contributions to this experiment, SSgt Lora Howell and SSgt Lloyd Tripp for their expert medical technician assistance and to the DES crew consisting of both Air Force and Raytheon personnel who supported the activity on a daily basis. The authors also wish to acknowledge the outstanding statistical analysis performed by Mr. Chuck Goodyear of Systems Research Laboratories.

The authors acknowledge the contributions of the Aircraft and Crew Systems Directorate, Naval Air Development Center, Warminster, PA for their guidance and support during the conduct of this study; in particular, Mr. Richard J. Crosbie, who loaned AFAMRL the NADC light bar which was duplicated and used in this study. Advice and instruction on the use of the Doppler flowmeter was offered by NADC personnel and greatly appreciated by AFAMRL personnel.

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INTRODUCTION

When the Dynamic Environment Simulator (DES), or the AFAMRL human centrifuge, was designed and then developed almost twenty years ago it was man-rated in 1969 with a maximum G-onset capability of approximately 0.75 G/sec (Table 1). Present operational aircraft such as the F-16 are capable of generating up to 6 G/second. Consequently, in order to study the effects of this high G onset environment, the centrifuge must be able to achieve higher onset rates.

Simulating high +Gz onset acceleration has become a more pressing issue because of the G-induced loss of consciousness (LOC) problem in the F-16. In one study, 20% of the F-16 pilots in one squadron who were polled anonymously admitted to a G-induced loss of consciousness (Gillingham, 1984). Several Class A F-16 mishaps, as well as other high performance aircraft mishaps, have been attributed to G-induced loss of consciousness.

This report documents a technique of generating high rates of acceleration onset on the DES and presents the results of an experiment to measure Gz-tolerance using this technique.

TABLE 1. DES SYSTEM CHARACTERISTICS

Physical Characteristics	
Rotating Structure Weight	180 tons
Radius from Center of Arm Rotation to Center of Gondola	19.0 feet
Interior Diameter of Gondola	10.0 feet
Radius from Center of Arm Rotation to Center of Aft-Mounted Experiment Platform	21.5 feet
Operational Characteristics (Maximums)	
Main Arm	
Velocity	5.86 rad/s (56 rpm) 20 g horizontal at 19 feet
Acceleration	0.25 rad/s/s
Gondola (Cab)	
Velocity	3.14 rad/s (30 rpm)
Acceleration	6.28 rad/s/s
Fork	
Velocity	3.14 rad/s (30 rpm)

SECTION 2.0

GENERAL METHODS

This experiment was carried out in three stages. In each stage the subjects were given the same G profiles; however, as additional anti-G protection was added, each subject's G-tolerance improved accordingly.

2.1 CAB AND SEAT CONFIGURATION

The seat had a tilt back angle of 30° with the vertical and a seat back-seat pan angle of 90°. This seat had been used in other experiments and was chosen because it was of the approximate seat back angle of the F-16 and accommodated subjects so that their heads could be located as closely as possible to the cab axis of rotation (to minimize Coriolis effects).

The subject faced into the axis of rotation rather than in the normal position along the circumference of the arm-circle (Fig. 1). In this configuration, the subject experienced the acceleration vector along the positive X-axis (chest-to-back or eyeballs-in). After the desired final G level was achieved by main arm rotation, the cab was then pitched into the Gx vector, converting its whole body effect to that of +Gz (footward or eyeballs-down). Normal footward acceleration (+Gz) is used here as that acceleration normal to the seat platform in the cab. A side arm controller was installed and integrated with the dynamic light bar in order to control the lights on the bar.

2.2 SUBJECTS

The fourteen men who participated in this experiment were active duty Air Force personnel and experienced members of the AFAMRL centrifuge subject panel. All were briefed on the experiment and signed a consent form. Their ages ranged from 23 to 40 years (mean, 27 years). All were instrumented with a three lead EKG, which was used to record the EKG during the G epochs, and EMG (electromyogram) leads on the left tricep and bicep (to sense straining). Some subjects had a Doppler temporal artery flow meter transducer taped over the left or right forehead near the temple. All subjects wore an anti-G suit, a flight suit, boots, gloves and head set. The experimental seat was positioned in the cab with the backpan tilted 30° back from the vertical with the head/headrest position as close as possible to the cab's rotational axis (Fig. 1). Final Gz acceleration was measured normal to the platform on which this seat was bolted, analagous to the acceleration experienced by an F-16 pilot.

2.3 ACHIEVING THE HIGH +Gz ACCELERATION ONSET RATE

The high +Gz onset was achieved by first accelerating the main arm such that the subject received the G force from chest to back (+Gx) and then, at a predetermined arm speed, the cab was pitched into the G vector so that the force transitioned from the subject's +Gx to +Gz axis (Fig. 1).

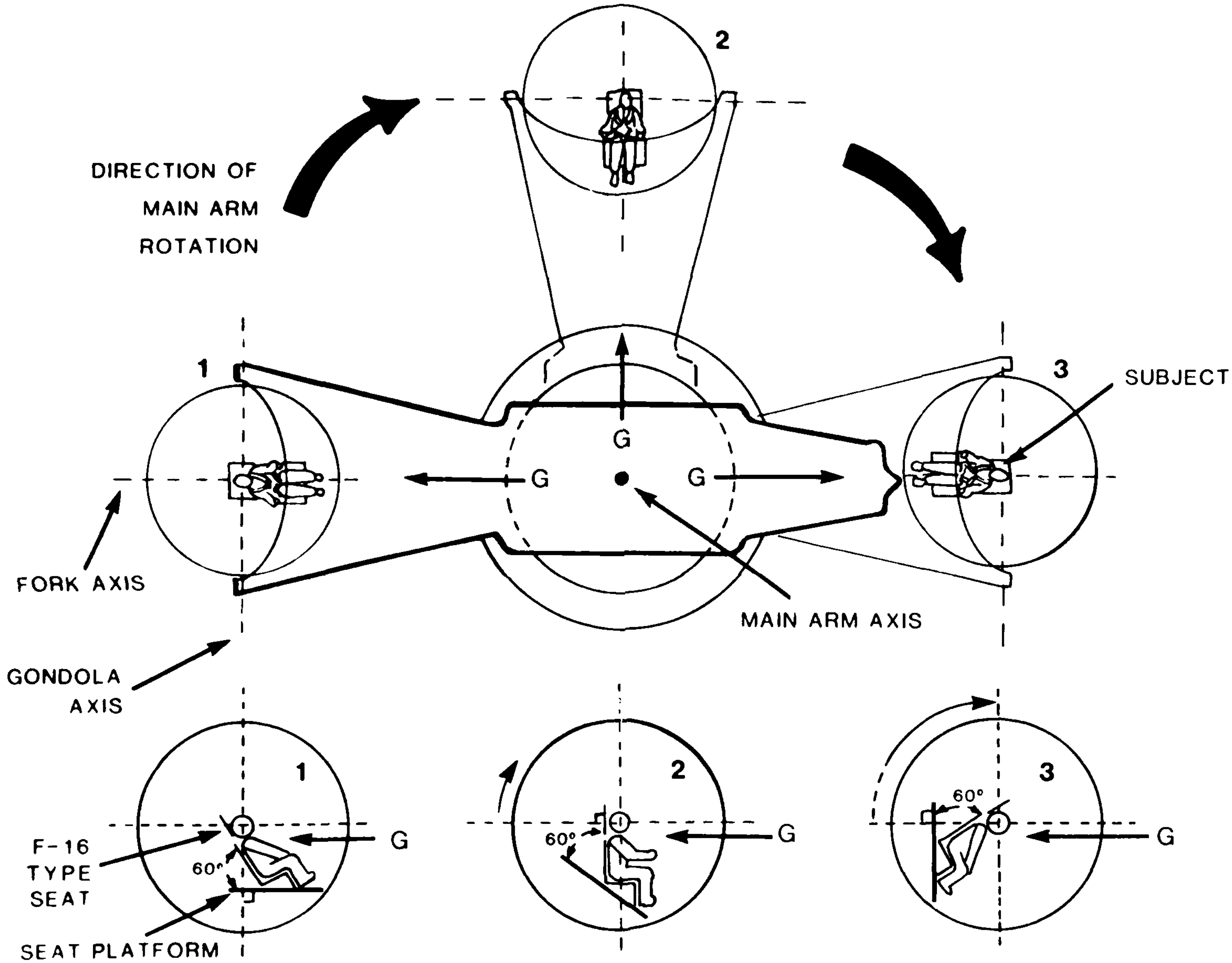

Figure 1 TOP VIEW OF DES AND SIDE VIEW OF GONDOLA ANGLES FOR 1) INITIAL WINDUP OF Gx ACCELERATION, 2) ORIENTATION OF GONDOLA JUST PRIOR TO PITCH-IN (HIGH Gz) MANEUVER AND 3) ORIENTATION OF GONDOLA TO G VECTOR DURING 15 SEC Gz PLATEAU.

The subject initiated this Gx to Gz maneuver by pressing the trim switch on the hand controller. After the main arm achieved the correct speed, a pair of LEDs on each side of a central LED would illuminate. This pair of LEDs would remain illuminated until the subject activated the trim switch and initiated, via computer control, the vectoring of the cab. This maneuver had to be initiated within a three second window or the main arm speed would return to baseline. This series of events required some training and many subjects had to repeat profiles during their earlier runs.

Fig. 1 illustrates this series of cab orientations. During baseline, the subject would be in the normal cab position, with the seat platform parallel to the building floor and the G force (excluding the earth gravity +1Gz) directed out from the main arm (position 1). During Gx wind-up, the cab was gimballed 30° toward the centrifuge's center so that the subject was experiencing +Gx only and no -Gz.

The anti-G valve was positioned perpendicular to the seat platform so that during Gx wind-up the valve would not open prematurely due to the Gz component when the cab was pitched into position 2 (Fig. 1). This was not totally successful as the valve did pick up enough of a Gz component to open partially, as can be seen in Fig. 8 in the G-suit pressure trace as the first hump at approximately the 3.5 psi.

Initially, negative Gz was a problem during the run-up because the first few subjects were accelerated with the seat in the 30° seatback angle configuration. The -Gz component lifted the subjects out of the seat and induced a mild slowing of the heart rate which could have been potentially dangerous at higher arm speeds. This -Gz component was avoided by positioning the subject normal to the centripetal acceleration during the Gx wind-up (position 2 Fig. 1).

2.4 MEASURING +Gz TOLERANCE

The light bar (Fig. 2) was the principal device used to measure +Gz tolerance. The dynamic peripheral light bar (Fig 2) was similar to that developed by Cohen (1983) and used by Crosbie (1982, 1984) but differed in that a pair of flickering light emitting diodes (LEDs) on opposite sides of the bar were used to indicate the extremities of the subject's peripheral visual field.Peripheral light loss (PLL) was defined as that cone of vision which subtended less than 60° on the light bar. When the subject moved his LEDs into this 60° field, the computer would terminate the run and return the centrifuge to the baseline (+1.4Gz).

2.5 ACCELERATION PROFILES

The first level was 2.5 Gz. The period of transition from Gx to Gz was held constant throughout the experiment at 3.0 secs. Subjects remained at each peak Gz level for 15 seconds, or until they developed PLL. The medical monitor and/or test director intervention could also terminate the run. After each 15 sec G epoch, the cab would vector back into a resultant 1.64 G (1.4 Gz, 0.85 Gx) baseline attitude, where the subject would rest for at least two minutes. If the subject tolerated the 15 sec G-epoch, then he would be exposed to another G-epoch 0.5G higher. This process would continue until PLL occurred (Fig. 3).

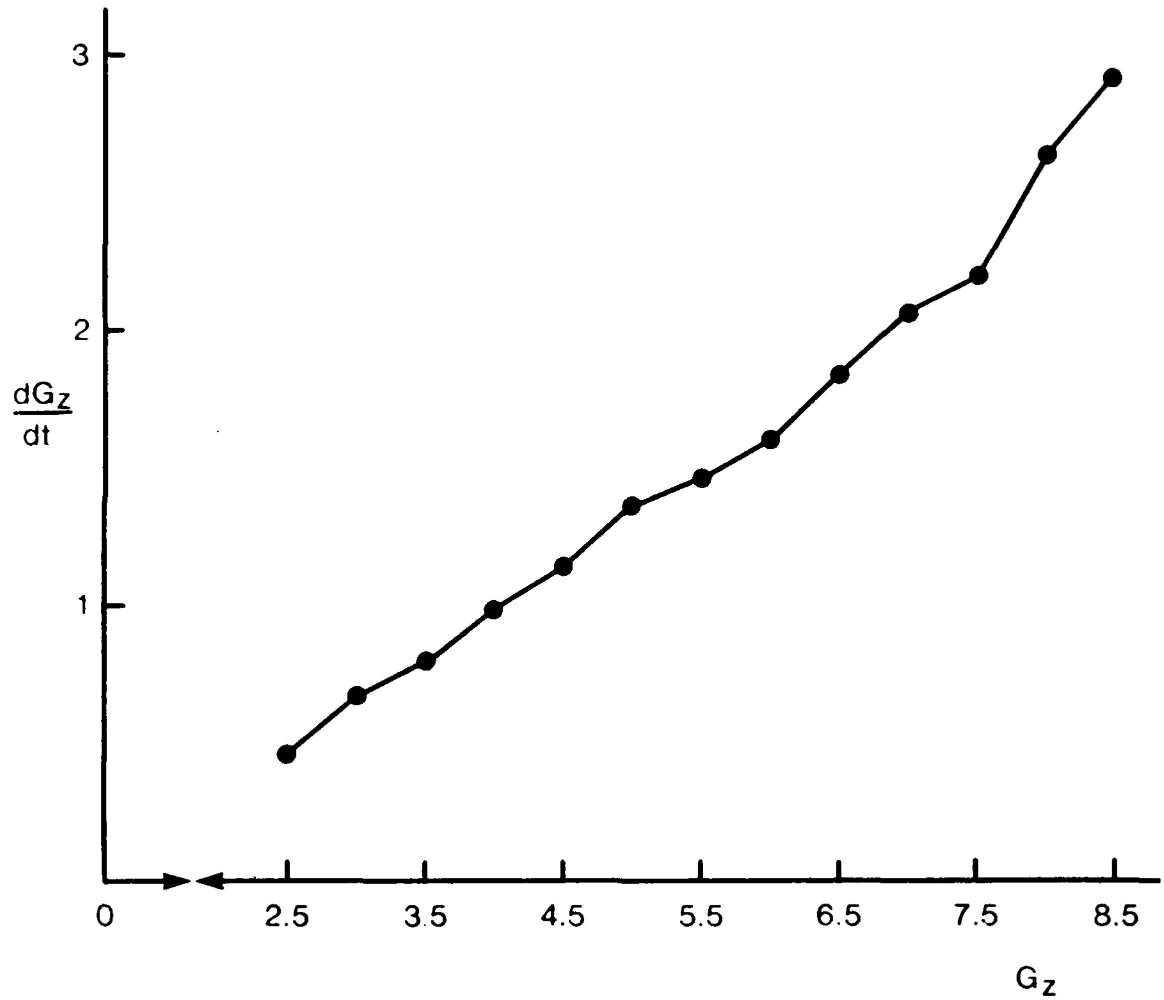

Figure 7. $\frac{dG_z}{dt}$ VS Gz

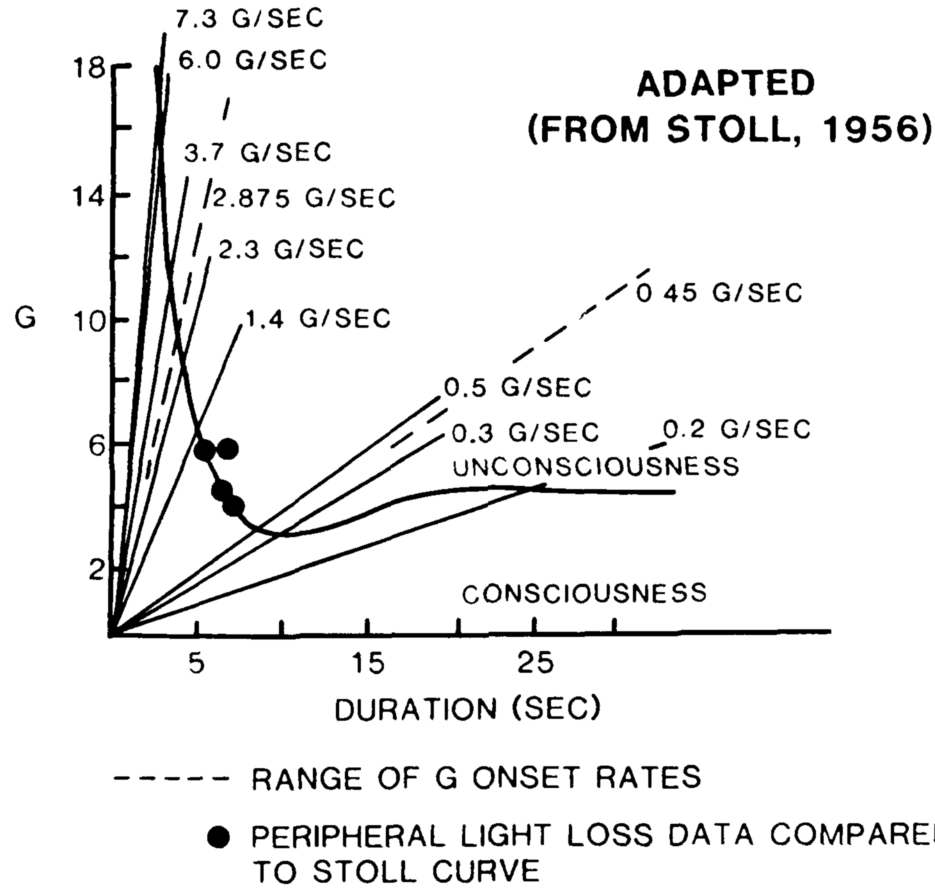

Figure 6. UNPROTECTED HUMAN ACCELERATION INTENSITY/DURATION BLACKOUT TOLERANCE CURVES COMPARED WITH VARIOUS ACCELERATION ONSET RATES. (DASHED LINES REPRESENT RANGE OF G ONSET RATES INVESTIGATED IN THIS EXPERIMENT. DOTS REPRESENT AVERAGE G TOLERANCES OF 15 UNPROTECTED/RELAXED SUBJECTS WHO LOST PERIPHERAL VISION OVER THE RANGE OF 3.0-4.5 G.)

used by Crosbie (1982). G tolerances of 15 subjects (including the eleven who completed this experiment) are plotted on the Stoll curve (Fig. 6). These four points represent average tolerances for fifteen relaxed and unprotected subjects who lost peripheral vision at 3.0 G (0.65 Gz/sec), 3.5 G (0.775 Gz/sec), 4.0 Gz (0.975 Gz/sec), or 4.5 G (1.15 Gz/sec). These data represent PLL and not blackout and were obtained in a reclined seat; they tend to fall on the Stoll Curve in the region indicated. Gz onset rates higher than 2.875 Gz/sec were not investigated in this experiment however higher onset rates are possible with the DES; 5 and 6 Gz/sec onset rates can be obtained at G levels greater than 4 G. A follow-on study investigating a new G-valve design used 3 Gz/sec onset rates (Van Patten, 1984).

Doppler signals from the superficial temporal artery were technically inadequate. We were unable to obtain consistent, reliable signals from the device; none of our traces was comparable to those published by other researchers (Crosbie, 1982, 1984; Rositano, 1980). Our traces (Fig. 8) at best only showed trends and could not be used to show significant differences between normal and reduced blood flow at eye level as previously reported (Crosbie, 1984). We have since discovered that the probes issued with the equipment were ineffective in recording termporal blood artery flow; newer probes are giving much better, clearer signals.

The light bar and associated closed loop DES control system was successful. The device proved to be an accurate and reliable metric for peripheral light loss. No subject lost consciousness; several lost central vision (blackout) and all lost peripheral vision into the 60° cone.

phase of the experiment; that phase in which G-protection provided by the straining maneuver was measured. Previous work has shown that +Gx acceleration has a relatively minor effect on cardiac hemodynamics (Wood, 1961 and Glaister, 1970). Subjects exposed to +5 Gx for ten minutes had no systematic change in stroke index (the volume of blood pumped with each beat of the heart, adjusted for the subject's body surface area), or peripheral vascular resistance, and only a minor increase (20%) in cardiac output (the volume of blood pumped by the heart each minute). In the first minute of the 5 Gx epoch, heart rate increased by 35 beats per minute and blood pressure increased only by 17mm Hg (Wood, 1961). Glaister found at +5Gx the anterior lung margin was unperfused in some subjects and the extreme back of the lung was unventilated in all subjects (Glaister, 1970). Since stroke index and cardiac output did not dramatically change, a major blood shift probably does not occur with +Gx accelertion. Thus, prior to the transition to +Gz, and commencement of blood pooling in the lower body, a relative baseline (1 Gz) blood distribution existed. In addition, the physiological effects of +Gx acceleration using this technique were present for each test conditon and, as a result, if a comparison between test conditions is made, the +Gx effects on the individual cancel out. Similar results were found in follow-on studies using this technique (Van Patten, 1984).

The G tolerance data collected in this experiment compared favorably with the literature (Crosbie, 1982, 1984; Gillingham, 1974). The Day III G tolerance was generally higher than that found in the referenced literature and can be attributed to several reasons. Subjects were allowed to commence their straining maneuver during the wind-up of the centrifuge in Gx prior to reaching peak arm revolution and then pitching the cab into the arm's axis. Because the valve was opening prematurely, there was "ready pressure" in the anti G-suit prior to the Gx to Gz maneuver. This tended to raise the G tolerance. In addition, a 30° reclined seat was used which has been shown to increase G tolerance (Rogers, 1973). Subjects began each phase at the 2.5 G level and progressed up to their final, protected, non-straining G tolerance limit before they commenced their straining epochs. They were given at least two minutes rest between each run and many subjects took more time (never more than 4 minutes) at the higher G levels.

The valve was receiving some antecedent Gz during Gx wind-up because it was perpendicular to the platform and not the acceleration vector (Fig. 1). It was observed that when the cab was vectored into the pre-transition position (Fig. 2, position 2 at bottom) the anti-G valve was experiencing +Gz force and was pre-inflating the G-suit.

The range of +Gz onset rates, duration of acceleration and plateau Gz levels were sufficient for bringing about PLL, a precursor to blackout and unconsciousness (Fig. 6). Since the time of transition, 3 seconds, was held constant in this experiment, the rate of change of Gz varied from 0.45 Gz/sec at 2.5 G to 2.875 Gz/sec at 8.5 G (Fig. 7). The range of +Gz onset rates is indicated by the dashed lines at 0.45 Gz/sec to 2.875 Gz/sec (Fig. 6). It was decided to hold the onset time of 3 seconds as a constant rather than the Gz onset rate because it eliminated the time of G exposure as a variable when the G plateau was varied. This is the same technique

SECTION 5.0

DISCUSSION

This experiment showed that high +Gz onset could be simulated on the DES and tolerated by the subjects by first accelerating the subject in the +Gx direction and then transitioning this vector to the +Gz axis by pitching the centrifuge gondola into the main arm's axis of rotation (Fig. 1).

Coriolis acceleration proved not to be a problem probably because the subject's ear-to-ear axis was placed as closely as possible to the cab's rotational axis. This reduced the moment arm acting on the semi-circular canals when the subject moved his head into a plane that was cutting across the plane of rotation of the main centrifuge arm. According to Coriolis' law (adapted from McLean, 1962) the absolute acceleration imparted to the vestibular system relative to the main arm and cab is

$$\bar{a}_v = (\bar{a}_{v/arm})_t + (\bar{a}_{v/arm})_n + (\bar{a}_p)_t + (\bar{a}_p)_n + 2\bar{w} \times \bar{V}_{v/arm}$$

where

$(\bar{a}_{v/arm})_t$ = acceleration of the vestibular system (considered a point in this analysis) relative to the main arm of the centrifuge.

$(\bar{a}_v/arm)_n$ = acceleration of the vestibular system normal to its path along the main arm.

$(\bar{a}_p)_t$ = tangential component of the acceleration of a point P on the main arm which coincides with the vestibular system at the instant involved.

$(\bar{a}_p)_n$ = normal component of the acceleration of the point M on the main arm which coincides with the vestibular system at the instant involved.

$2\bar{w} \times \bar{V}_{v/arm}$ = supplementary or Coriolis acceleration where the angular velocity of the main arm w is crossed with the velocity of the vestibular system as it moves away from the center of main arm rotation along an axis through the cab.

Since the vestibular system was placed as closely as possible to the cab's axis of rotation relative to the arm, the $\bar{V}_v$/arm term approaches zero and there is no Coriolis acceleration term in the absolute acceleration equation. Had the vestibular system been off of the cab axis, this term would be nonzero.

One possible problem with this technique is the effect of +Gx acceleration on the subjects prior to the +Gz exposure. We found only a 14 beats/min. average increase in heart rate during the +Gx acceleration over the resting baseline in the final acceleration profile of the most grueling

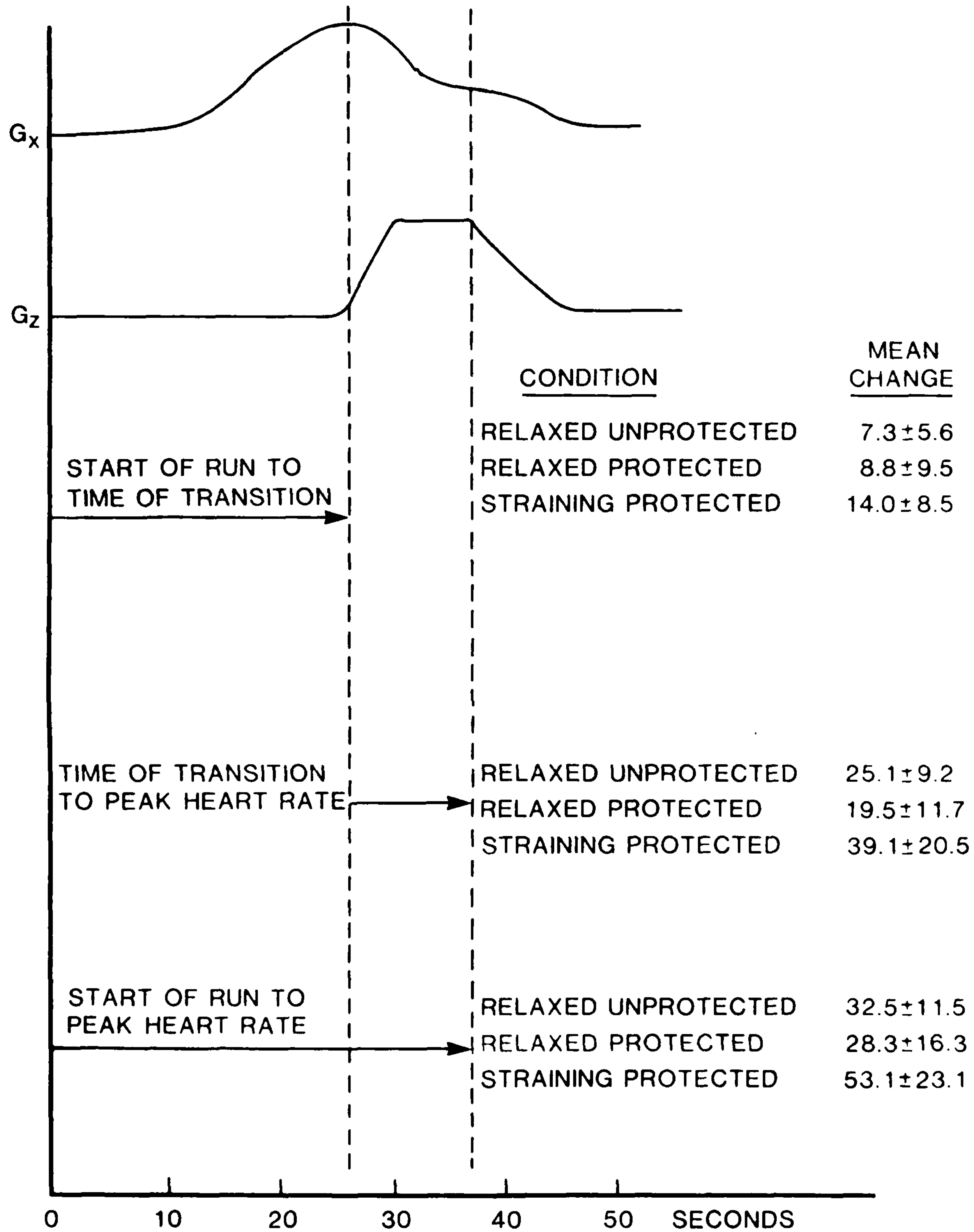

Figure 5. HEARTBEAT INCREASE (BEATS/MIN) DUE TO G_x AND G_z STRESS

SECTION 4.0

RESULTS

No significant physiological problems were identified with this method of generating high G onset. Three subjects out of twenty initially screened reported mild transitory motion sickness during the indoctrination profiles but did not have any further difficulties on subsequent data profiles. Two others reported Coriolis or tumbling sensations during the experiment; however, none of these incidents were severe enough to terminate any profile. Two subjects reported pain in the right elbow at 6.0 Gz. One subject reported a tingling sensation in his lips, nose and ears, during several runs starting at the 4.5 Gz level. Several subjects commented on the +Gx chest pressure as G values increased to 8.5 Gx but no one specifically complained about the force.

G tolerance limits as well as means and standard deviations for all subjects are listed in Table 2 and shown in Fig. 4. Most subjects experienced PLL within the first ten seconds of their final Gz exposure (Table 3). The F-test showed a significant difference among all three of these conditions ($p = .0001$). All three conditions or phases were significantly different from each other.

For all three time periods considered and for all three anti-G protection scenarios of the heart rate data (Fig. 5) there was a significant increase in heart rate for all subjects from the start of the run to the time of transition and to the time of peak plateau. The changes for each condition were not significantly different from each other; however, for the segment from time of transition to the plateau peak, the change was significantly greater for relaxed unprotected than for relaxed protected ($p<0.004$). An average heart rate time history is plotted in Fig. 8.

SECTION 3.0

STATISTICAL METHODS

An analysis of variance (ANOVA) was performed using Gz tolerance as the dependent variable, with subject and condition as the factors. Fourteen subjects participated in the study. The analysis was performed on the eleven subjects who participated in all three conditions.

For each difference in the heart rate data, the Wilcoxson signed rank test was used. This test was preferred over an analysis of variance (ANOVA) or t-test since these tests assume normality and much of the data was not normally distributed. In all cases the null hypothesis, H_o:change in heart rate = 0 was tested against the alternative hypothesis, H_a:change in heart rate = 0.

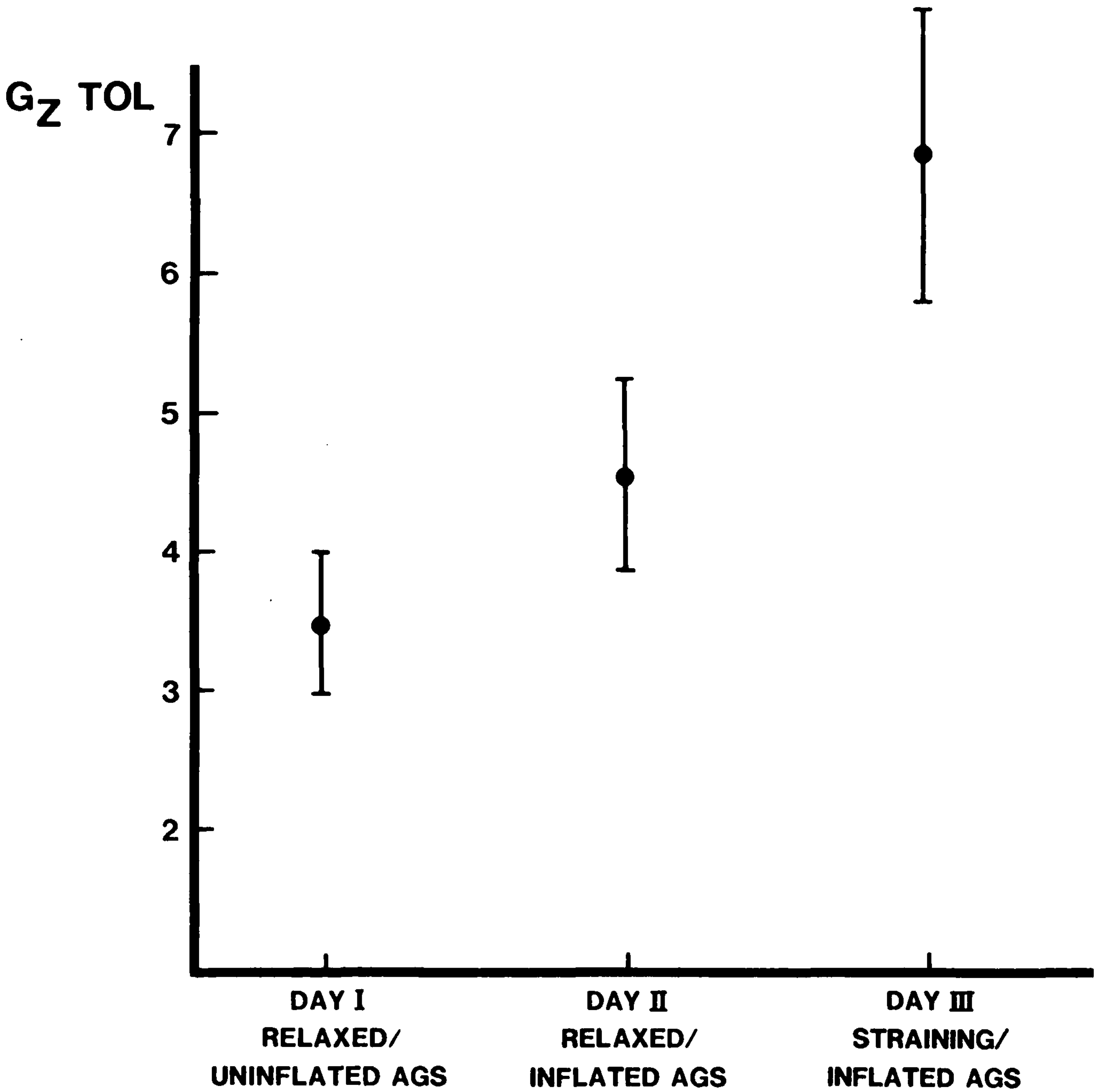

Figure 4. MEAN G TOLERANCE TO HIGH +Gz ONSET

TABLE 3. TIME TO PLL FROM TRANSITION Gx to Gz (secs)

(G LEVEL IN PARENTHESIS)

SUBJECT	DAY I	DAY II	DAY III
1	8.0 (4.5)	10.6 (5.5)	10.72 (6.0)
2	7.4 (3.5)	7.68 (4.0)	7.6 (7.0)
3	8.0 (3.0)	9.28 (3.5)	8.76 (5.0)
4	7.36 (3.5)	7.24 (4.5)	8.88 (7.0)
5	--	10.2 (5.0)	9.4 (6.5)
6	8.88 (3.5)	4.6 (5.0)	7.12 (8.5)
7	8.4 (4.5)	14.6 (5.5)	9.84 (8.5)
8	10.92 (3.5)	7.96 (5.0)	9.08 (6.5)
9	10.28 (4.0)	9.48 (5.0)	8.8 (8.0)
10	8.28 (4.0)	9.84 (6.0)	--
11	10.12 (3.5)	7.72 (5.5)	--
12	11.68 (3.0)	10.56 (4.5)	7.28 (7.5)
13	10.72 (4.0)	5.48 (5.0)	10.5 (7.5)
14	8.68 (3.5)	7.0 (5.5)	8.6 (6.5)

In order to document the effect of this technique of simulating high +Gz onset on the cardiovascular system prior to arriving at a peak +Gz level, heart rates were recorded for each subject at the following times during their final epoch where PLL occurred:

(1) Start of the run.
(2) Time of transition from Gx to Gz.
(3) Peak heart rate during plateau at +Gz.

TABLE 2. G TOLERANCE LIMITS (G's)

SUBJECT	DAY I (Relaxed/Uninflated AGS)	DAY II (Relaxed/Inflated AGS)	DAY III - (Straining/Inflated AGS)
1	4.22	5.29	5.80
2	3.21	3.71	6.71
3	2.72	3.26	4.74
4	3.20	3.70	6.75
5	--	4.78	6.26
6	3.25	4.63	8.20
7	4.23	5.41	8.27
8	3.3	4.72	6.25
9	3.79	4.76	7.74
10	3.73	5.77	--
11	3.28	5.21	--
12	2.82	4.29	7.2
13	3.80	4.65	7.29
14	3.24	5.19	6.24
*	3.44±.51	4.51±.70	6.84±1.06

*Means and Standard Deviations ($F = 91.3$, $P = .0001$)
Note: $P < .05$ implies the change is significant. $N = 11$

2.6 EXPERIMENTAL PROCEDURE

Subjects were given indoctrination runs to familiarize them with the Gx to Gz gimballing and how to control the light bar. The profiles used during the indoctrination runs were the same as those described above except that indoctrination profiles started at 2.0 Gz instead of 2.5 Gz. No subject was allowed to start participation in the experiment until he was comfortable controlling the light bar and experiencing the acceleration profile.

The experiment was conducted in three phases. In Phase I, subjects wore a standard anti-G suit (CSU-13 A/P) that was not connected to a G-valve and remained as relaxed as possible during the runs. In Phase II, the anti-G suit was connected to a standard Alar servo valve (ALAR 8000A), which had an inflation schedule of 1.5 psi per G starting at 2.2 G. In this phase, the subjects were also relaxed. In Phase III, the subjects wore an anti-G suit connected to the standard valve and performed a straining (L-1 or M-1) maneuver. The subjects began the profiles at 2.5 G in a relaxed condition and continued until they were at the G level at which they had previously (Phase II) developed PLL. At this level, they started the straining maneuver at the initiation of the Gz onset. The profiles were continued at 0.5 G intervals until the subjects developed PLL.

2.7 MEASURING G TOLERANCE AND HEART RATE

+Gz tolerance was defined as the +Gz level the subject successfully completed (15 secs plus 3 sec rise time) plus that fraction of the next higher Gz level during which the subject lost his peripheral vision (Crosbie, 1982).

18 seconds was selected instead of 21 seconds (which would have included the 3 second offset time) in order to compare G-tolerances with those from other studies and facilities (Crosbie, 1982). 21 seconds is probably a better tolerance period to use since the subjects must strain at the higher G levels during the offset in order to maintain clear vision. G tolerance limit was defined here by Crosbie's technique (Crosbie, 1982).

where G_{TL} = Subject's G tolerance limit
G_{TL1} = Highest G level tolerated for complete G profile
T = Time of G profile, rise plus plateau time (18 secs)
ΔT = Time from start of G before PLL occurs
ΔG = Incremental G above G_{TL1}, 0.5 G in this experiment

$$G_{TL} = G_{TL1} + \frac{\Delta T}{T} \quad (\Delta G)$$

Thus, if a subject sustained a 4.5 G run and experienced PLL after 7 seconds at the 5 G level, his G tolerance was calculated to be,

$$G_{TL} = 4.5 + (10/18)\ (0.5) = 4.78 \qquad \text{(I)}$$

G tolerance for all of the subjects was recorded (Table 2 and Fig. 4). The time to loss of peripheral vision for each epoch was also recorded (Table 3).

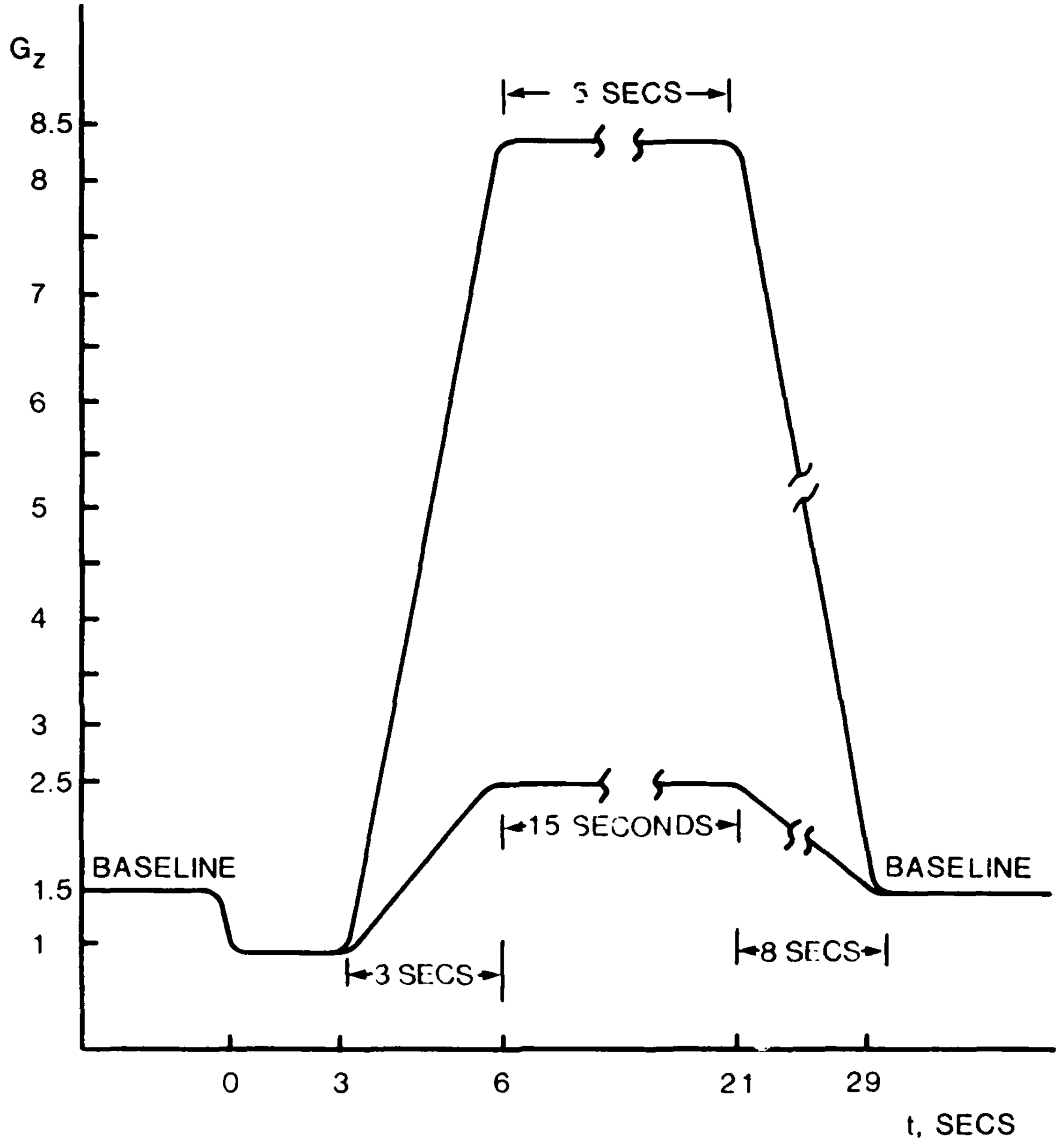

Figure 3. G PROFILES USED IN THE STUDY

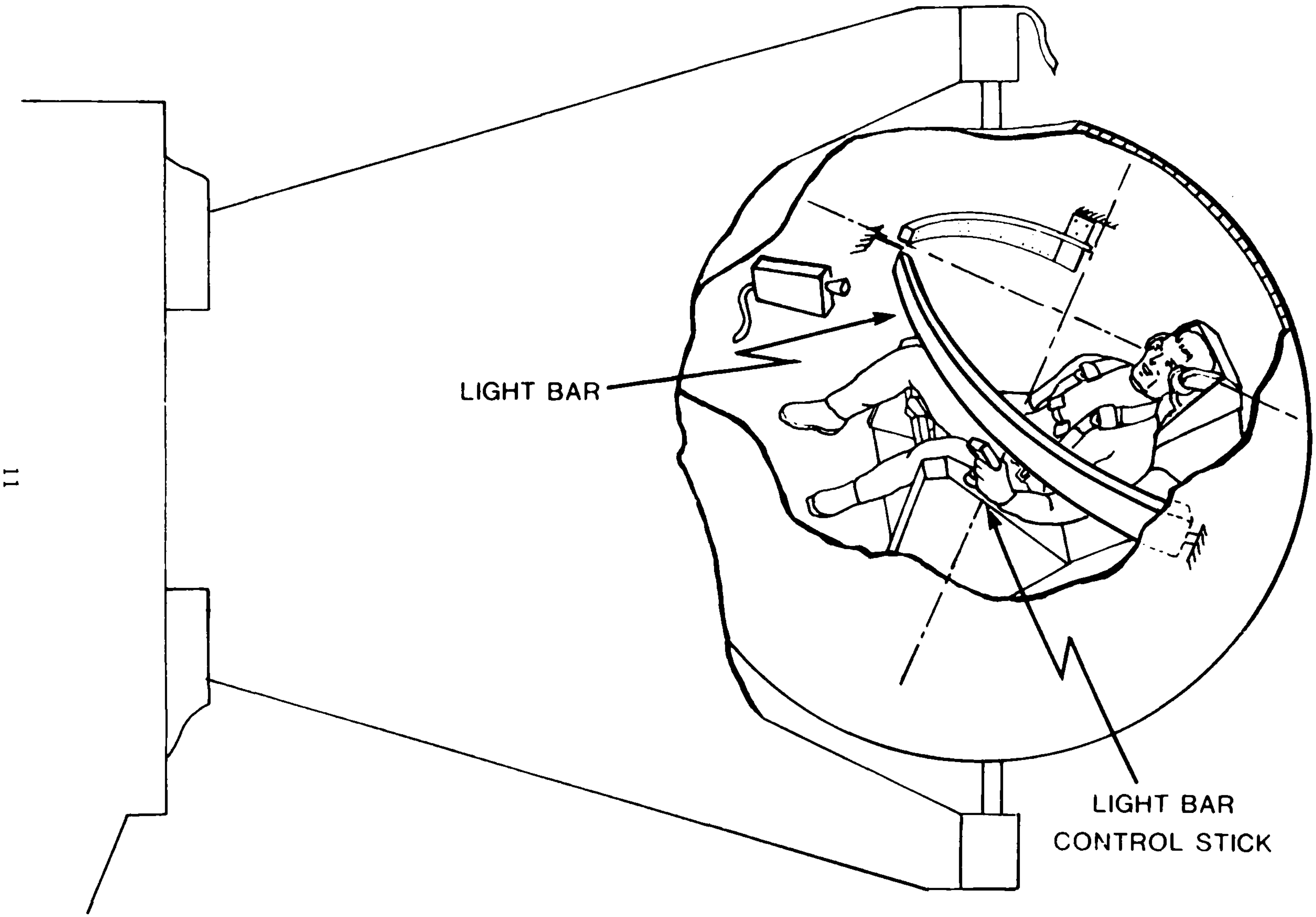

Figure 2. THE REPPERGER LIGHT BAR SHOWN IN RELATION TO THE SUBJECT AND DES GONDOLA.

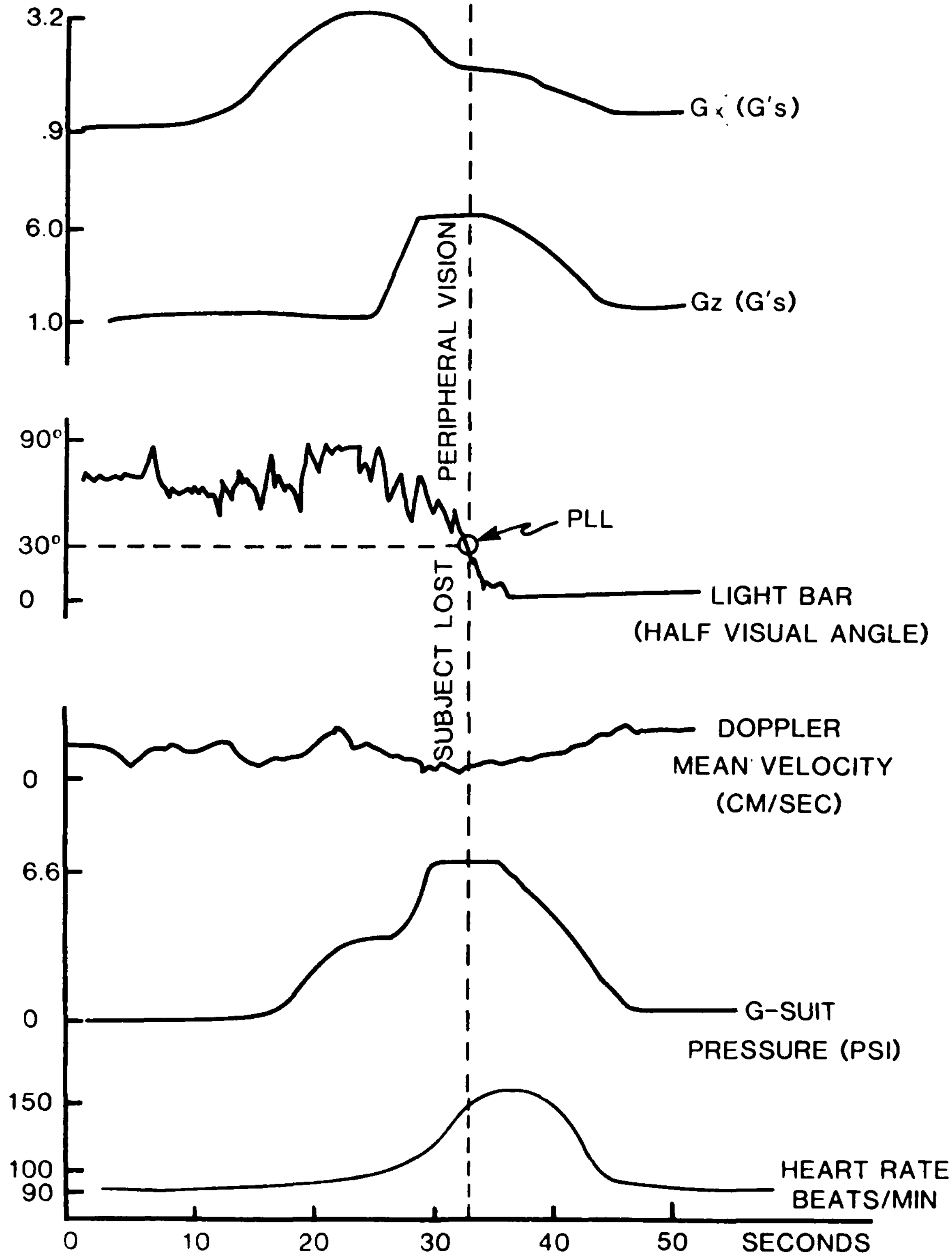

Figure 8 TYPICAL STRIP CHART RECORDING FROM EXPERIMENT

SECTION 6.0

SUMMARY

This report documents a series of experiments to investigate the utility of the Dynamic Environment Simulator (DES) in the conduct of high acceleration onset studies. Because the three axis device is limited to approximately 1 G/sec onset in the main arm axis of rotation, a unique approach of coupling the more responsive cab-axis degree of freedom to the main arm motion was evaluated. By building up the G stress in the subject's Gx axis (eyeballs-in) via the main arm and then pitching the subject into the resultant Gx vector in a footwards orientation, the resultant, final G vector was in the +Z (eyeballs down) direction; this Gx to Gz transition was evaluated at various rates greater than 1G/sec and approaching 3G/sec.

Eleven subjects completed all three phases. A peripheral vision tracking light bar was built and used throughout the experiment with reliable results. All elevent subjects lost peripheral vision but none lost consciousness.

Using the DES in the unique fashion described above and the peripheral light bar output as controlled by each subject, the average Gz value for peripheral light loss without an inflated G-suit or straining was $3.44 \pm .51$ Gz. This tolerance increased to $4.51 \pm .7$ Gz for non-straining subjects protected by G-suit only and to 6.84 ± 1.06 Gz for those subjects who strained (usually L-1 maneuver) and had G-suit protection. These results compare favorably with values obtained by other researchers at different facilities and demonstrate the utility of this technique to simulate high +Gz onset acceleration.

A standard anti-G valve and anti-G suit were used in the experiment. Subject electrocardiograms were recorded on the Brush recorder, digitally and on FM tape. Two closed circuit TV cameras were focused on the subject and the face of the subject was recorded on video tape during all runs.

This technique of increasing the +Gz level by 0.5 G increments proved to be a safe and reliable means for determining individual G tolerance. In addition, it proved to be an excellent means for evaluating the technique described herein for simulating high +Gz onset.

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